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USE OF STENCHES AS A WARNING IN MINES

BY

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USE OF STENCHES AS A WARNING IN MINES.

By S. H. Katz, V. C. Allison, and W. L. Egy.

INTRODUCTION.

In mines liable to fires from electric wiring, open lights, spontaneous combustion, or other causes a means of warning the miners in order that they may reach a place of safety and avoid being trapped by the fire is of great importance. This is particularly true in some metal-mining districts where mine fires are frequent. The shafts there are usually deep and heavily timbered, so that the fires spread rapidly and air currents of high velocity may carry the poisonous fumes from the fire to many parts of the mines in a very short time.

Electric gongs have been tried in metal mines and also in the coal mines of Illinois, but have not been satisfactory. The sound can not be heard far, and the circuits are kept in repair with difficulty because of the excessive corrosion of the wires and because of accidental grounding. As a means of signaling, some mines in the West have placed three-way valves, essentially the same as the stop and waste cocks in water lines, at various points in the compressed-air line. Turning one of these valves closes the line from the compressor and releases the air from that branch of the pipe. Interruption of the flow of air is the signal for the men to leave the mine. This method, too, is not satisfactory, because accidental interruptions cause needless confusion and stopping of work.

At the Belgrade mine fire at Biwabik, Minn., on February 1, 1919, water was turned into the compressed-air line to warn the miners of danger. When the miners noticed the water they ran from their working places and warned the others. The lives of all the men but one, who lost his senses through fear, were saved.

Telephones have been placed in many large mines, the system running to the vicinity of all the important workings. This means hitherto has been found the most effective for warning miners.

The Butte & Superior Mining Co., of Butte, Mont., J. L. Bruce, general manager, tried the method of introducing valeric acid into the intake of the air compressor, and found that only a few minutes were required for the pungent odor of this substance to reach the farthest working parts of the mine. The method was brought to the attention of G. S. Rice, chief mining engineer of the Bureau of Mines, by Daniel Harrington, mining engineer of the bureau, and at the instigation of Mr. Rice an investigation of various stenches was undertaken.

Stenches as a warning have a decided action; they exert a positive effect because of their offensiveness. When miners smell the disagreeable stenches described in this paper, they instinctively desire to obtain pure air at once. If the miners can not obtain pure air readily, however, they can tolerate the stenches without much discomfort.

The velocity of air through compressed-air lines in metal mines is usually hundreds or even thousands of feet a minute, so that transmission of a stench is rapid. Warning by stenches is particularly adapted to mines equipped with compressed air. In coal mines, where only the ventilating current is available for carrying a stench, the average velocity is low, of the order of 200 feet a minute or less. If the velocity of the air in a compressed-air line is rapid, a small quantity of material would give more effective warnings than the same quantity in a ventilating current, because of being liberated in concentration at the points where most needed, and being less diluted with air. However, the method may be useful in some mechanically ventilated mines where compressed-air lines are unavailable.

The stenches were first tried in the laboratory and those that seemed most promising were then tested in the experimental mine of the Bureau of Mines. Later tests were made in the large metal mine of the North Butte Mining Co., at Butte, Mont., the Central mine of the North Star Mining Co., and the Empire mine of the Empire Mining Co., both of Grass Valley, Calif. This paper gives the results of the tests, with a discussion of their practical application to operating conditions.

Of the chemicals tried, butyl mercaptan is the best adapted for the purpose in view, but as yet there is no commercial source of this substance. Ethyl mercaptan, butyric acid, and amyl acetate, which may be obtained of chemical supply houses or manufacturers, give excellent results.

ACKNOWLEDGMENTS.

Acknowledgment is made to George S. Rice, chief mining engineer of the Bureau of Mines, who had the experiments made at the experimental mine; to A. C. Fieldner, supervising chemist of the Pittsburgh mining experiment station of the bureau, who helped in devising laboratory apparatus and in selecting and obtaining suitable chemicals; to Daniel Harrington, mining engineer, for detailed description of conditions in certain metal mining districts and for

directing the tests performed in the North Butte mine; to B. W. Dyer, mining engineer, and the crew of mine rescue car 5, for conducting the tests in the Central and Empire mines and for help in conducting the tests in the North Butte mine, and to Messrs. N. B. Braly, general manager, and L. D. Frink, general superintendent, of the North Butte Mining Co., for their time, interest, and expense incurred in the conduct of the tests in their mine, and to Mr. Arthur Foote, manager of the North Star Mining Co., and to Mr. L. W. Nobbs, general superintendent of the Empire Mining Co., for their interest and cooperation.

NECESSARY PROPERTIES OF STENCHES.

In order that it be useful for the purpose in view, the chemical used should have the properties described as follows:

NONTOXICITY.

Obviously a stench should not be toxic. In order to make the warning harmless, under any possible conditions of mismanagement, nontoxicity or absence of injurious effects on the human system is the first necessity. Also, the vapor must have no lachrymatory or other irritating effect on the eyes, lest miners become unable to find their way.

MODERATE VAPOR PRESSURE.

The vapor pressure of a chemical may be considered a measure of the rate of evaporation. The higher its vapor pressure, the more rapidly a substance evaporates and the greater the quantity of it that a given volume of air will hold. Moderate vapor pressure is needed to prevent the possibility of an excessive concentration of the chemical in any part of the air of a mine. Although it is advantageous to be able to create in the escaping air such concentrations as when diluted with the surrounding air in the mine, will give the desired effect, yet the maximum concentrations possible should be low enough to prevent harmful effects, even if breathed undiluted for a time. By the use of chemicals with a lower vapor pressure, the breathing of vapors in excess of certain comparatively low concentrations is automatically impossible.

ODOR.

The odor preferably should be disagreeable, rather than pleasant, in order to be most effective as a warning, and should be distinctive, so that there would be no danger of mistaking it.

AVAILABILITY.

Substances that can be readily obtained in the market at moderate prices are to be given preference; but if such substances do not answer the purpose, those that may be prepared without difficulty in the chemical laboratory are to be desired.

EXAMINATION OF ODORS IN THE LABORATORY.

APPARATUS.

The apparatus used for the examination of the stenches, the "odorometer," is shown in figure 1. It consisted of a number of flow meters of the Venturi type, so arranged as to pass a measured volume of air, flowing at a uniform rate, over or through the substance, and then to mix this concentrated air-vapor mixture with pure air in various measured quantities flowing at uniform rates. The concentration of the substance was measured by determining the loss in weight after the measured air had passed through it. From this data and the total volume of air with which the substance was mixed, the concentration in parts per million, grams per cubic foot, and cubic centimeters per 1,000 cubic feet were calculated. The air with the admixed chemical was passed through a rubber tube with a glass funnel at the open end. The funnel, when placed over the nose, enabled the operator to smell the mixture before it became contaminated with room air.

The apparatus was placed in a hood provided with strong suction and the room was well ventilated to prevent the operator continually smelling the odor, as this would tend to lessen his sensitiveness to differences in the degree of concentration.

SCALE OF INTENSITY FOR ODORS.

An arbitrary scale for odors of five degrees of intensity was adopted. The degrees are called: (1) Detectable, (2) faint, (3) quite noticeable, (4) strong, (5) very strong.

Only one inhalation was used to determine intensity. The position on this scale of any strength of odor depends on the sensibility and judgment of the individual, but with one person conducting a test from start to finish, the method has been found decidedly satisfactory.

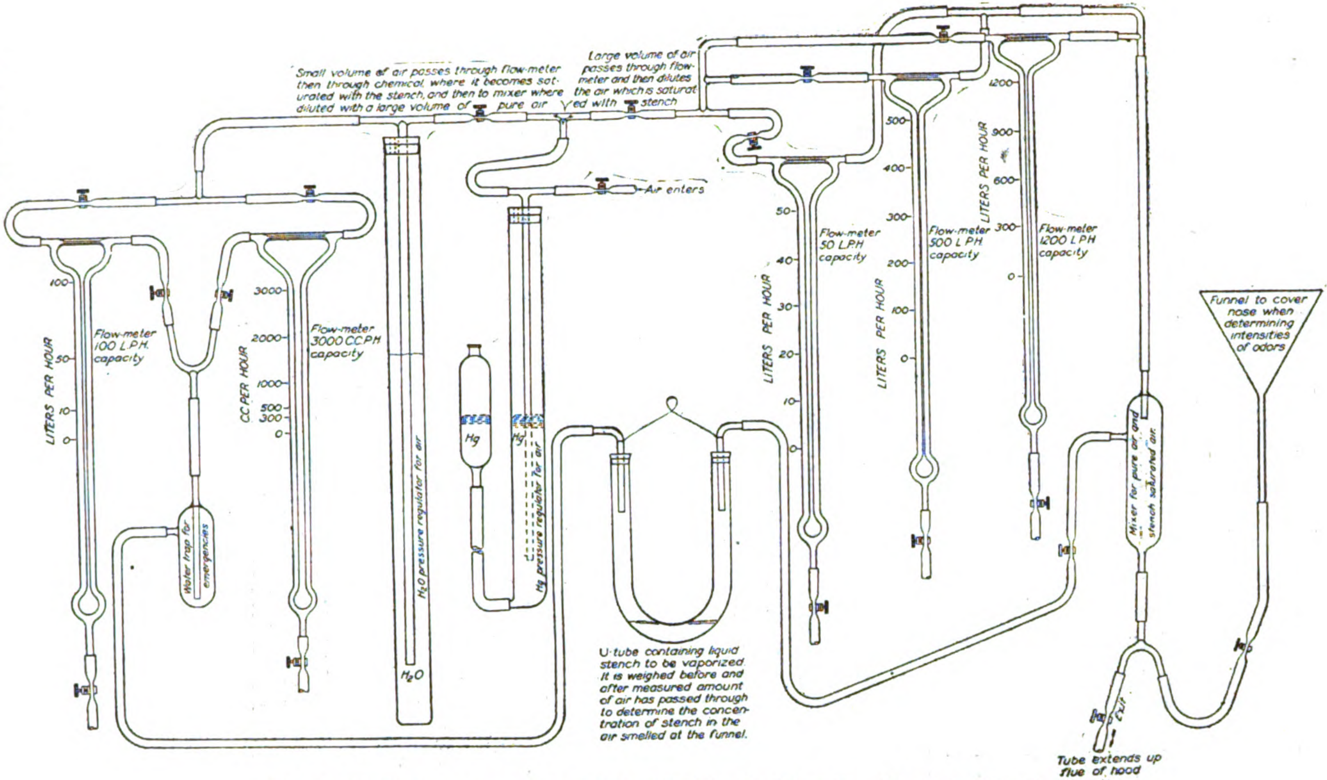

Small volume of air passes through flow-meter then through chemical, where it becomes saturated with the stench, and then to mixer where diluted with a large volume of pure air
Large volume of air passes through flow-meter and then dilutes the air which is saturated with stench
Air enters
Flow-meter 100 L.P.H. capacity
LITERS PER HOUR
100
50
10
0
Water trap for emergencies
Flow-meter 3000 CC.P.H capacity
CC PER HOUR
3000
2000
1000
500
300
0
H_2O pressure regulator for air
H_2O
Hg
Hg
Hg pressure regulator for air
U-tube containing liquid stench to be vaporized. It is weighed before and after measured amount of air has passed through to determine the concentration of stench in the air smelled at the funnel.
Flow-meter 50 L.P.H capacity
LITERS PER HOUR
50
40
30
20
10
0
Flow-meter 500 L.P.H capacity
LITERS PER HOUR
500
400
300
200
100
0
Flow-meter 1200 L.P.H capacity
LITERS PER HOUR
1200
900
600
300
0
Mixer for pure air and stench saturated air
Funnel to cover nose when determining intensities of odors
Exit
Tube extends up flue of hood

FIGURE 1.—"Odorometer," the apparatus used in the laboratory for measuring odors.

RESULTS OF LABORATORY INVESTIGATIONS.

The substances examined in the laboratory were as follows:

Substances examined.

Amyl acetate.
Ethyl acetate.
Amyl alcohol.
Butyric acid.
Valeric acid.
Ethyl ether.
Butyl mercaptan.
Isobutyl mercaptan.
Ethyl mercaptan.
Propyl mercaptan.
Amyl thioether.
Ethyl thioether.
Allyl esothiocyanate.
Methyl esothiocyanate.
Amyl isovalerate.
Carbon tetrachloride.
Chloroform.
Iodoform.
Artificial musk.
Nitrobenzene.
Phenyl isocyanide.
Pyridine.
Methyl salicylate.
Oil of peppermint.

Table 1 gives the results of the examination of those substances found useful for mine warnings. Figure 2 shows the results graphically. Table 2 gives the chemical, physical, and physiological properties of the substances. From figure 2 it is interesting to note that the cumulative effects of increasing concentration vary greatly with the different substances. It is seen that butyl mercaptan gives a strong odor at very low concentrations, and because of its low vapor pressure at ordinary temperatures and its harmlessness, seemed most promising for use in mines. However, this chemical can not be obtained in the market at the present time.

Ethyl mercaptan is nearly as good for this purpose, and may be purchased in the market. This substance has the disadvantage of a high vapor pressure at ordinary temperatures, so that excessive quantities can be introduced into the mine, if the operation is not conducted properly. Recent tests made at the American University experiment station of the Chemical Warfare Service, United States Army, on the toxicity of the vapor of ethyl mercaptan have shown that the vapor is harmless.

Of the various substances tested and found useful, butyric acid and amyl acetate are most readily available. The former may be obtained from chemical supply houses. The latter is artificial banana oil, used in paints and lacquers. It may be obtained from paint dealers or chemical supply houses.

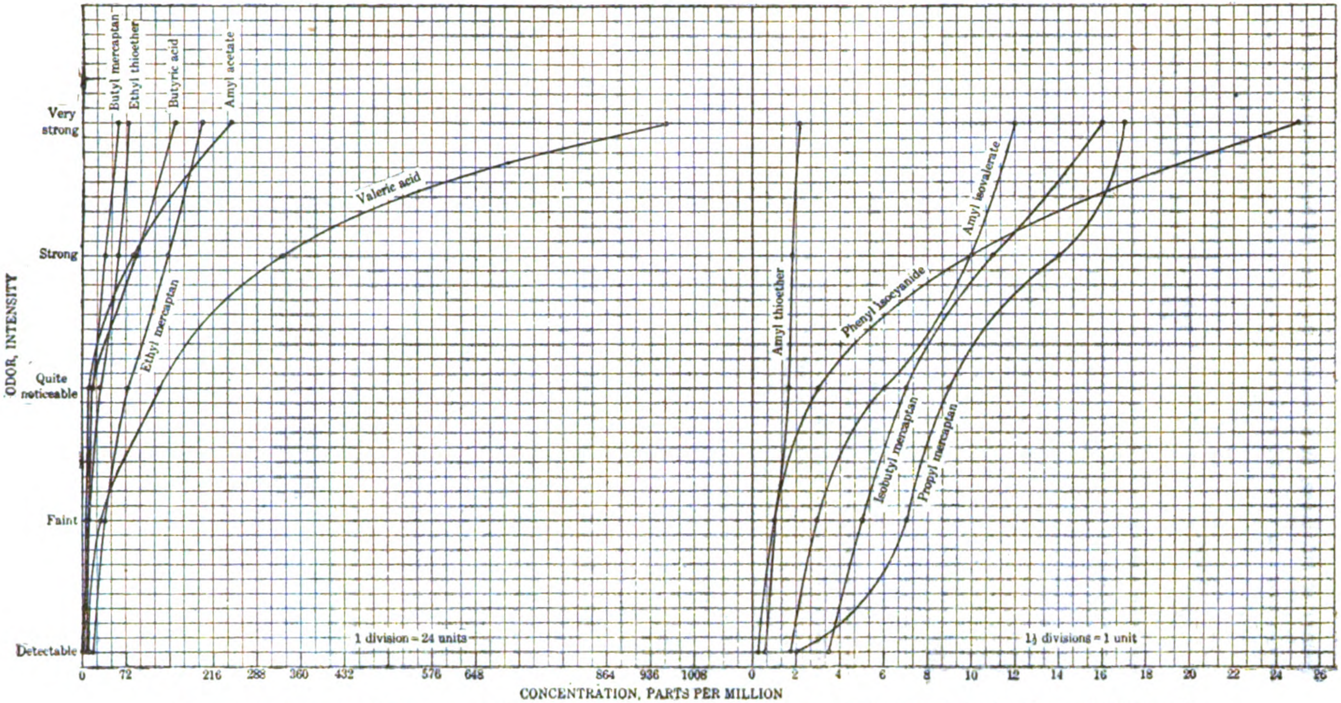


FIGURE 2.—Curves showing intensity of odors against concentration, as measured with the "odorometer."

TABLE 1.—*Results of measurements of the intensity of various stenches **with the** odorometer.*

Volume of Substance, as a Perfect Gas, per Million Volumes of Air.

Name.	Intensity of odor.				
	Detectable.	Faint.	Quite noticeable.	Strong.	Very strong.
Amyl acetate	7	10	13	90	246
Butyric acid	2.4	6	18	91	161
Valeric acid	7	29	125	332	962
Butyl mercaptan	6	12	18	38	56
Isobutyl mercaptan	3.5	5	7	11	16
Ethyl mercaptan	18	35	73	141	198
Propyl mercaptan	2	7	9	14	17
Amyl thioether	.2	1	1.6	1.7	2.2
Ethyl thioether	3	12	29	61	74
Amyl isovalerate	1.7	3	6	10	12
Phenyl isocyanide	.5	1	3	10	25
Oil of peppermint	....	....	....	....	....
Milligrams per Cubic Foot of Air.					
Amyl acetate	1.1	1.5	2	14	38
Butyric acid	.3	.6	2	9	16
Valeric acid	.8	3.4	15	39	114
Butyl mercaptan	.5	1.0	2	3	5
Isobutyl mercaptan	.2	.5	.7	1	2
Ethyl mercaptan	1.3	2.5	5	10	14
Propyl mercaptan	.2	.6	.8	1.2	1.6
Amyl thioether	.04	.2	.3	.4	.5
Ethyl thioether	.3	1.2	3	6	8
Amyl isovalerate	.4	.5	1	2	2.3
Phenyl isocyanide	.06	.1	.4	1	3
Oil of peppermint	.68	.9	3	9.5	9.9
Cubic Centimeters of Liquid per 1,000 Cubic Feet of Air.					
Amyl acetate	1.3	1.7	2.3	16	43
Butyric acid	.3	.6	2	9	17
Valeric acid	.8	3.6	16	41	121
Butyl mercaptan	.6	1.2	2.3	3.4	6
Isobutyl mercaptan[a]	.2	.6	.8	1	2
Ethyl mercaptan	1.6	3	6	12	17
Propyl mercaptan[b]	.2	.7	.9	1.4	1.9
Amyl thioether[c]	.04	.2	.3	.4	.5
Ethyl thioether	.4	1.4	4	7	10
Amyl isovalerate	.5	.6	1	2	3
Phenyl isocyanide	.06	.1	.4	1	3
Oil of peppermint	.7	1	3	10	11

[a] Specific gravity assumed to be 0.850.
[b] Specific gravity assumed to be 0.848.
[c] Specific gravity assumed to be 0.900.

TABLE 2.—*Chemical, physical, and physiological properties of odors useful for mine warnings.*

Name.	Formula.	Character of odor.	Specific gravity.	Boiling point, °C.	Melting point, °C.	Physiological properties of vapor.	Remarks.
Amyl acetate	$CH_3COO(CH_2)_4CH_3$	Banana oil	0.875	148	[a] −75	Harmless	Pleasant to most persons. Distasteful to some.
Butyric acid	$CH_3(CH_2)_2COOH$	Very disagreeable, like stale butter.	.960	162.3	−7.9	do	
Valeric acid	$CH_3(CH_2)_3COOH$	do	.942	186.4	−58.5	do	
Butyl mercaptan.	$CH_3(CH_2)_3SH$	Very disagreeable, similar to garlic or onions.	.858	97	......	do	
Isobutyl mercaptan.	$(CH_3)_2CH_2CH_2SH$	do	......	87	......	Unknown.	Probably harmless.
Ethyl mercaptan.	CH_3CH_2SH	do	.838	37	−144.4	do	Do.
Propyl mercaptan.	$CH_3(CH_2)_2SH$	do	......	67	......	do	Do.
Amyl thioether.	$(CH_3(CH_2)_4)_2S$	Very disagreeable.	......	216	......	do	Do.
Ethyl thioether.	$(CH_3CH_2)_2S$	do	.836	92	−99.5	do	Do.
Amyl isovalerate.	$(CH_3)_2CH.CH_2COO\text{-}C_5H_{11}$	Disagreeable, but somewhat etherial.	.855	190	......	Harmless	
Phenyl isocyanide.	$C_6H_5.NC$	Very disagreeable, resembles skunk odor.	.977	165	......	Unknown.	Do.
Oil of peppermint.	......	Pleasant	.910	......	......	Harmless	

[a] Thick.

TESTS IN MINES.

Tests of stenches were conducted in the experimental mine of the Bureau of Mines, located 1 mile south of Bruceton, Pa., and in the North Butte mine at Butte, Mont.

DESCRIPTION OF THE EXPERIMENTAL MINE.

The experimental mine of the Bureau of Mines, shown in figure 3, consists of two parallel drift entries, 1,308 feet long, called the "main entry" and the "air course," and one pair of butt entries, driven to the left at points 850 and 900 feet from the mine opening, with a set of five rooms turned from No. 1 butt. The air enters the air course at a point 135 feet from the mouth, from a gallery slant 350 feet long. For these tests the fan was run as a blower, the air current intaking on the air course and returning on the main entry.

The compressed-air line extends in the air course to a point 650 feet from the mouth (A 650), where it passes into an expansion tank and water trap, with a small opening for the discharge of the accumulated water. The tank is placed in the cut-through, about 15 feet from the ventilating current. From this point the line extends

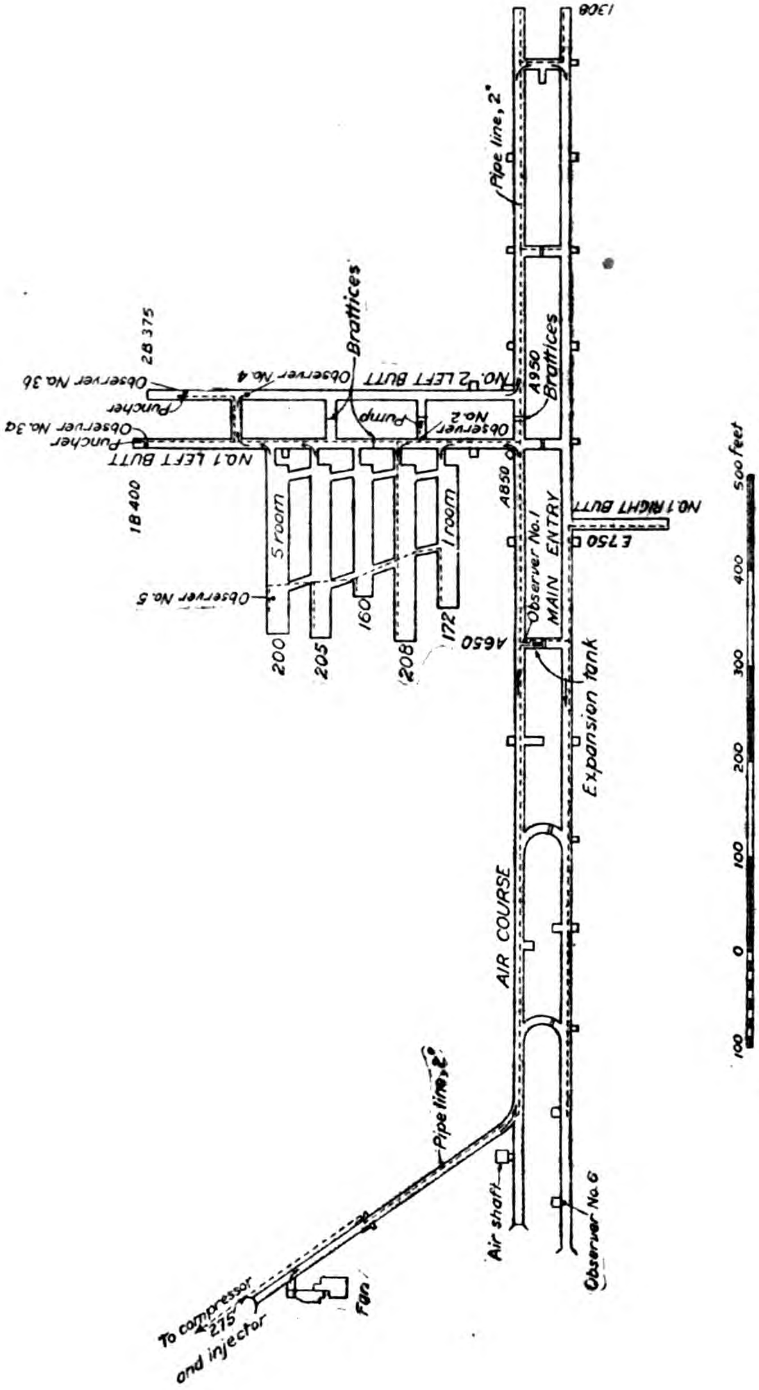


FIGURE 3.—Plan of experimental mine, showing conditions during tests of stenches.

along the air course, up No. 1 butt, and through the rooms, as shown in figure 3. In the first cut-through between the butt entries the air operates a small reciprocating water pump. The line is 2-inch pipe throughout.

INJECTOR FOR LIQUID STENCHES.

The liquid chemical was dropped into the compressed-air line just outside the engine room containing the compressor and receiver.

The mechanism used for injecting the chemicals into the air line is shown in figure 4 and in Plate I. It consisted of a pressure injector, such as is used for oiling steam-engine cylinders, which was screwed into an enlarged section of pipe built into the air line. Pressure was admitted to the space above the liquid; a needle valve on the bottom regulated the flow of liquid into the pipe. Directly underneath the injector a wire screen was placed in the pipe, slanting upward in the direction of the air flow. A second screen was placed about one-fourth of an inch behind the first screen in order to catch any drops which might be thrown through the first screen before being volatilized. The container being calibrated, the volume of liquid present at any instant could be read directly by means of a vertical scale on the outside of the glass. By taking frequent readings of the quantity remaining in the container and timing the flow with a stop watch the rate of injection of the substance into the air line could be carefully regulated. In these tests no attempt was made to determine whether all of the substance was volatilized as rapidly as it dropped on the screen, but the laboratory experiments indicate that it may have been volatilized.

This injector is simple in construction and could be easily built into any pipe line. In practice any type of valve could be substituted for the needle valve. It would be advisable to place such an injector in a by-pass with valves at both ends, in order that contamination of the air could be stopped at any instant, even though some of the liquid still remained upon the screens.

METHOD OF CONDUCTING EXPERIMENTS IN THE EXPERIMENTAL MINE.

A measured amount of the liquid chemical was placed in the injector, and at a prearranged time this was allowed to drop on the screen in the air line, the rate of injection being controlled by adjusting the needle valve.

The air was allowed to discharge into the mine at the positions of the observers, as shown in figure 3. A compressed-air puncher was operated at the face of one or the other butt entries (observers 3a and 3b), the pump in No. 1 butt was started (observer 2), and valves at the expansion tank at A 650 (observer 1), and near the face of 5 room (observer 5), were opened just enough to allow a

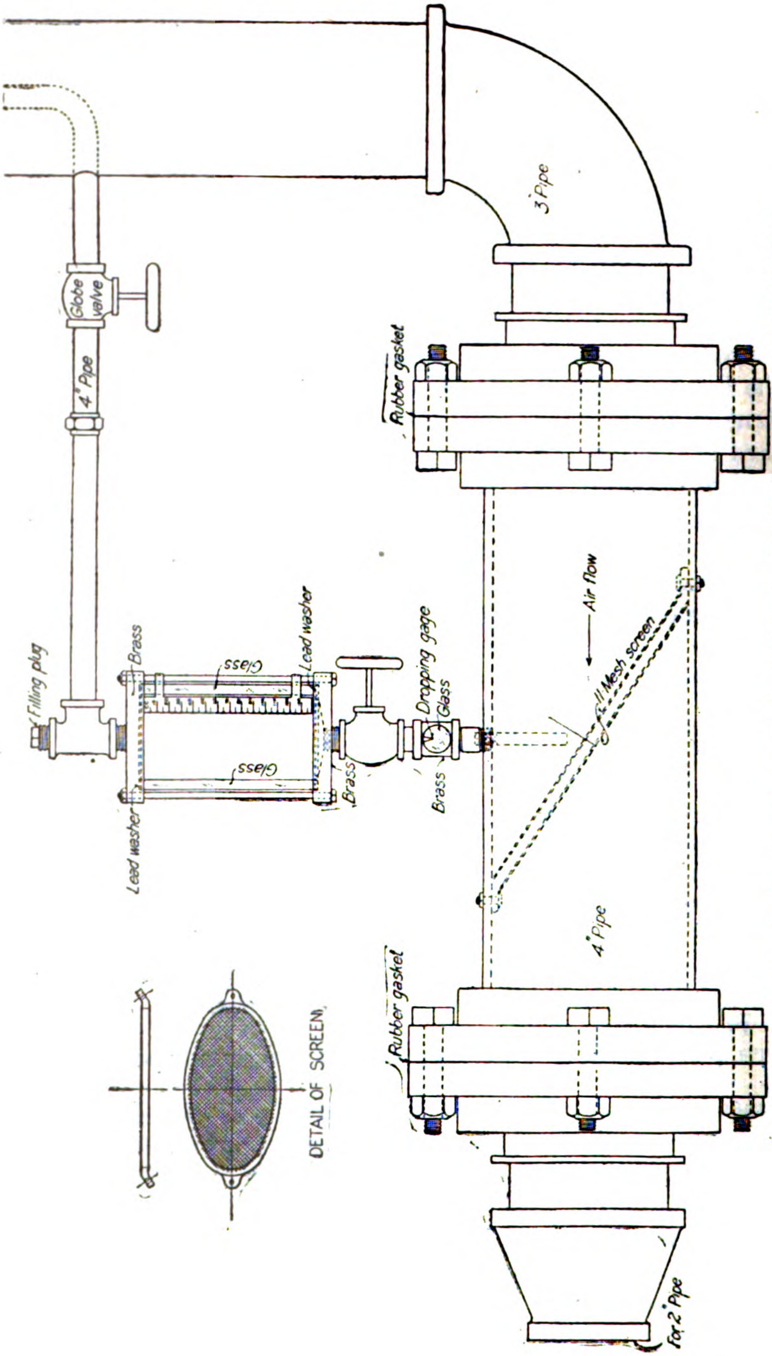
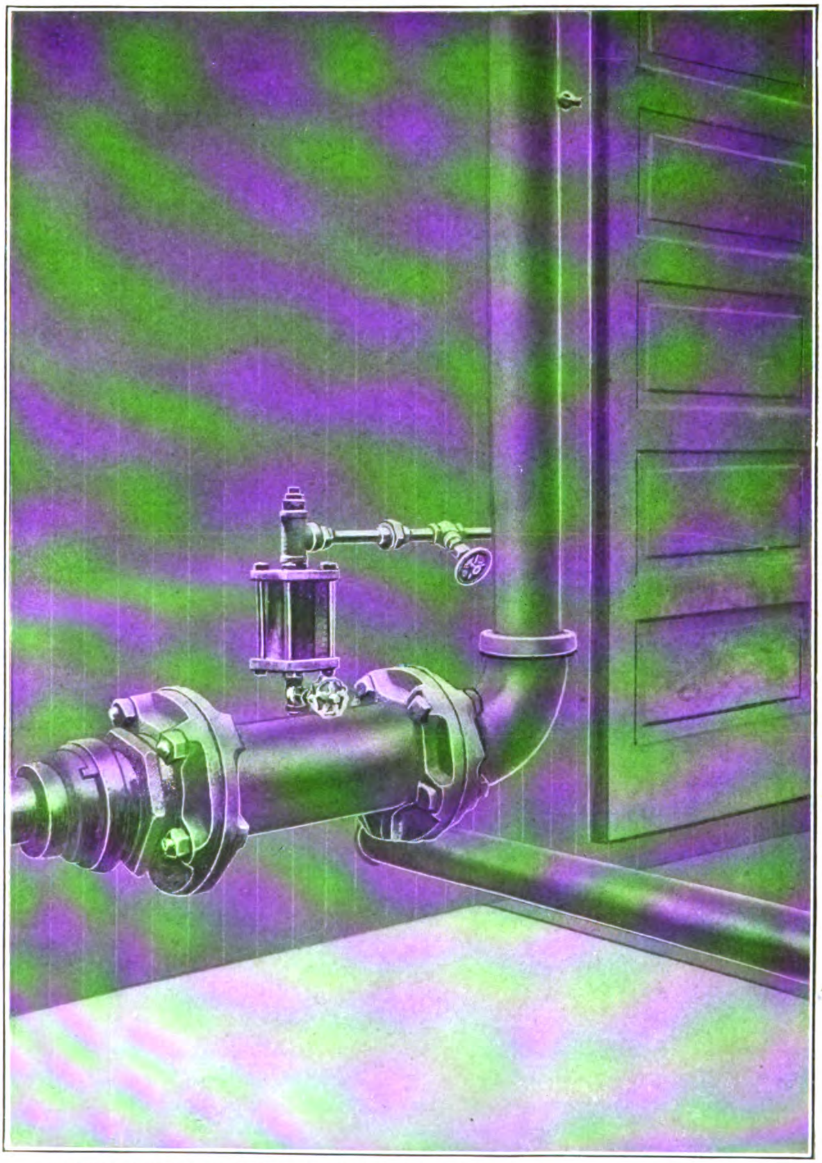


FIGURE 4.—Details of the apparatus used for injecting stenches into the compressed-air line.



APPARATUS FOR INJECTING STENCHES INTO COMPRESSED-AIR LINES.

slight leak. In some of the tests, when the puncher could not be operated, the valve was opened to allow about the same quantity of air to pass as when the machine was in use. Each of these observers was placed about 15 feet from the outlet of the pipe, except at the puncher where the men were operating the machine in the usual manner. In addition observer 4 was placed in No. 2 butt, just outby the last cut-through, and another (No. 6) at the mouth of the return entry. In order to reach this last observer, the odor had to be carried by the ventilating current a distance of 1,950 feet—that is, from the junction of No. 2 butt, and the last cut-through, near observer 4. The time at which the odor reached each station was noted, the watches of all observers having been previously compared. The observers were instructed to record in each test the time at which the odor became so strong that it would be observed with certainty, even if it were not being expected.

A series of tests was first run with five different substances, butyl mercaptan, valeric acid, amyl acetate, butyric acid, and ethyl mercaptan, to determine their relative suitabilities.

DESCRIPTION OF TESTS IN THE NORTH BUTTE MINE.

Tests were conducted at the Granite Mountain shaft of the North Butte mine, Butte, Mont., to determine the effectiveness of stenches under actual working conditions in a large metal mine. The following extracts are from a report by Daniel Harrington, mining engineer of the bureau, who directed the tests:

> The North Butte mine, chosen in which to make the test, is one of the largest and most extensive mines in the Butte district, having active workings at practically all horizons from the surface to the 3,600-foot level and an output of over 2,000 tons per day. Several different veins are worked, and the mine has upward of 30 miles of levels and many additional miles of raises, manways, stopes, etc. Over 1,000 men, about 500 being miners, are employed underground on two shifts, when the mine is producing at a maximum rate, though the underground force at time of making the tests was probably less than 700, probably 375 being miners.
>
> Approximately 10,500 cubic feet of free air is compressed by three air compressors near the Speculator shaft and conveyed by pipe about 700 feet to the collar of the Granite Mountain shaft, thence down the Granite Mountain shaft to the various levels, the air pipe on various levels being 2 and 3 inches in diameter. All working faces are supplied with compressed air, and when working at maximum capacity the three compressors are unable to supply enough air to keep the pressure in the underground lines much above 50 pounds, and the pressure frequently is less than 50 pounds. At time of making the stench tests only two compressors, with a capacity of about 7,000 cubic feet of free air per minute, were required, giving a surface air pressure of nearly 90 pounds and an underground pressure of about 80 pounds.
>
> From the above it will be seen that the velocity of compressed air in pipes would be much greater when the mine was working at maximum capacity (as in

the summer of 1918) than when the stench tests were made: hence stench odors would probably be transmitted to working faces more quickly under conditions of maximum ore production than the tests show.

The mine has about 350 compressed air drills at work when operating at maximum capacity, and at the time of making the tests probably 150 drills were in use. Drills will, in general, use about 50 to 80 cubic feet of air per minute, and a drill will average 1½ hours actual drilling (using compressed air) per 8-hour shift.

The mine is one of the best ventilated in the Butte district, having two upcast shafts, each with an electrically driven suction fan at the surface and one upcast shaft using natural ventilation. The main downcast shaft is the Granite Mountain, which distributes more than 82,000 cubic feet of air per minute to regions below the 2,000-foot level, as follows: 8,600 feet on the 2,200 foot level, 17,800 feet on the 2,400, 22,200 feet on the 2,600, 16,300 feet on the 2,800, and 17,200 feet on the 3,000-foot level. In addition, a small fan electrically driven forces air through canvas pipe from the 3,000-foot level to the faces of crosscuts between the 3,000 and 3,600 foot levels; and on various levels air is distributed to the faces of drifts, crosscuts, raises, and stopes by means of small fans and canvas pipes. The velocity of air in the canvas pipe ranges from 2,000 to more than 5,000 linear feet per minute. This mine is much better ventilated than most metal mines, but it should be borne in mind that the stench tests as conducted **were not in the slightest degree affected by the fan ventilation and the results attained would have been the same had there been absolutely no fan ventilation in the entire mine.** This is important, as it would be fatal to rely on fan ventilation to convey warnings in metal mines. Comparatively few metal mines make any attempt to insure air circulation at the working faces where most of the men would be working and where the warning would be most needed. The tests show that fan ventilation is not necessary to the success of stenches as warning in metal mines, the compressed-air system being sufficient in itself.

Through the kindness of Mr. N. B. Braly, general manager of the North Butte mine, an apparatus for introducing the stench had been placed in a building near the collar of the Granite Mountain shaft, the apparatus being so situated and constructed as to be of use permanently provided the tests were a success. Unfortunately, about 25 feet or more of 1-inch pipe intervened between the point of introducing the stench material and the point at which it reached the main air pipe. Tests 1 and 2 proved that the small amount of stench fluid, with essentially the same pressure both before and behind it would not be effective by the time it traversed this 25 feet or more of small pipe. After the second test I pointed out this to the general superintendent, Mr. L. D. Frink, and he had the introducing apparatus placed immediately over the main air pipe in such manner that every drop of the stench fluid immediately entered the main pipe. With this rearrangement of apparatus test 3 was a complete success.

DESCRIPTION OF TESTS IN THE CALIFORNIA MINES.

In order to try the stenches in different mineral mines and also under other difficult conditions, further tests were made in the following gold mines: The Central mine of the North Star Mining Co. and the Empire mine of the Empire Mining Co., both at Grass Valley, Nevada County, Calif. In the North Star mine amyl acetate was used; in the Empire mine, butyl mercaptan. The following quotation is from a report of the tests by B. W. Dyer, mining engineer of the bureau, who assisted in the tests:

> The Central and the North Star are two of the oldest gold mines in California and two of the five largest producers. The mines have deep shafts, long crosscuts, and extensive workings. On account of the small amount of timber used in these mines there is little chance of fire, but the management of both companies, after the tests were made, are going to have the injectors for introducing the stench made a permanent fixture and obtain a supply of stench material. Then, in the event of danger, the men can be quickly warned.
>
> To warn all places in their mines by sending men would take from one to three hours. With the stench, men in all parts of the mine got the warning in not more than 20 minutes, only those places where very little air was used requiring as much as 20 minutes for the stench to reach them.
>
> I stayed until the shift was hoisted after both tests and talked to the bosses and miners. All felt that the test was without doubt a success.

RESULTS OF MINE TESTS WITH DIFFERENT STENCHES.

The results of the tests in the mines with different stenches are given in Table 3.

The time values given for the different tests in the experimental mine appear to be rather inconsistent, but this variation is no more than would be expected in such circumstances. Some observers probably recorded the first detectable odor, whereas others waited for a stronger indication. The slowness of recording the presence of the valeric and butyric acids was due more to the failure to distinguish the odor, in small concentrations, from the normal mine odor than to any delay in the arrival of the vapor.

There was also some variation in the velocity of the compressed air through the pipe line, as indicated by the low pressures given in Table 3. This is particularly true of the tests with butyl mercaptan and butyric acid.

Reference to the plan of the experimental mine, figure 3 (p. 12), shows that the quantity of air in the ventilating current would have little effect on the strength of the odor as observed at the various stations, except those where observer 6, and particularly observer 4, were stationed.

In each of the three tests at the North Butte mine, the quantities of stench used were less than those recommended. Also, in two of these tests the long length of pipe through which the liquid had to pass to reach the air current was unfavorable to good results, because much of the liquid used simply wet the walls of the first pipe; then, too, the liquid required a much longer time to reach the air stream, and probably dripped into the air stream over a period much longer than the time required to leave the holder. Thus the concentration of stench in the air stream was reduced. In the test with amyl acetate, when the long preliminary pipe had been removed, the results were excellent.

TABLE 3.—*Results of mine tests with different stenches.*

TESTS IN EXPERIMENTAL MINE.

Material.	Quantity of liquid used, c. c.	Rate of injection.		Pressure on air line at compressor, pounds per square inch.	Estimated quantity of free air going through pipes, cubic feet per minute.	Estimated average velocity of air passing through pipes, feet per minute.	Quantity of air in ventilating current in mine, cubic feet per minute.	Average velocity of ventilating current, feet per minute.	Concentration in ventilating current.	
		C. c. per minute.	Ounces per minute.						Mg. per cubic foot.	C. c. per 1,000 cubic feet.
Butyl mercaptan	20	26.7	0.90	25	74	1,241	5,000	84	4.60	5.36
Ethyl mercaptan	20	31.3	1.16	65	88	738	5,650	95	5.01	5.98
Amyl acetate	35	32.8	1.11	70	50		5,000	84	5.68	6.49
Do	50	32.6	1.10	20	74	1,421	10,510	177	2.70	3.08
Butyric acid	35	24.2	.82	20	50	970	5,000	84	4.60	4.79
Do	150	86	2.9	70	64	493	6,120	103	13.3	13.9
Do	115	115	3.9	70	65	500	4,570	77	24.0	24.7
Valeric acid	35	30.4	1.03	70	50		5,000	84	5.67	6.02
Do	30	28.1	.95	68	83	669	8,550	144	3.07	3.26
Do	100	200	6.8	70	65					

Material.	Time required for stench to reach stations, in minutes and seconds.							Remarks.
	Observer 1: Station at A 650 (1,135 feet by pipe).	Observer 2: Station at 1 B 100 (1,470 feet by pipe).	Observer 3a: Station at 1 B 400 (1,760 feet by pipe).	Observer 3b: Station at 2 B 375 (1,785 feet by pipe).	Observer 4: Station at 2 B 290 (1,700 feet by pipe).	Observer 5: Station at 5 R 175 (1,485 feet by pipe, 300 feet by ventilating current; total, 1,785 feet).	Observer 6: Station at E O (1,760 feet by pipe, 1,950 feet by ventilating current; total, 3,710 feet).	
Butyl mercaptan	0:55	1:45		0:16	4:20	6:43	43:02	Odor strong and disagreeable.
Ethyl mercaptan	1:17	1:43		2:45	4:20	10:28	28:00	Odor strong and disagreeable; easily recognizable in small quantities.
Amyl acetate	3:03	10:37	9:15		12:00	20:23	49:00	Characteristic odor easy to detect, rather pleasant.
Do	0:57	0:48		2:20	6:20	4:28	20:00	
Butyric acid	Not detected.	Not detected.		1:56	5:47	19:40	53:48	Observers not sure of easy recognition.
Do	2:51	7:08		8:08	10:08		a 26:00	
Do	5:51	9:08		7:08	14:08	27:21	a 25:00	
Valeric acid	17:56	12:35	2:56		27:56	50:19	45:54	Do.
Do	10:33	11:33		16:06	20:06	35:33	46:00	
Do	b 7:00	7:00		4:00	7:00	9:30	No test in 30 minutes.	

TESTS IN COMMERCIAL MINES.

Mine and material.	Quantity of liquid used, c. c.	Rate of injection.		Pressure on air line at compressor, pounds per square inch.	Estimated quantity of free air going through pipes, cubic feet per minute.	Estimated average velocity of air passing through pipes, feet per minute.	Quantity of air in ventilating current in mine, cubic feet per minute.	Average velocity of ventilating current, feet per minute.	Concentration in ventilating current.	
		C. c. per minute.	Ounces per minute.						Mg. per cubic foot.	C. c. per 1,000 cubic feet.
North Butte mine:										
Ethyl mercaptan	180	180	6.1	90	7,500	c 300	82,000	2 to 12	1.7	2.0
Butyl mercaptan	500	500	16.9	85	7,000	....	82,000	2 to 12	4.8	5.6
Amyl acetate	1,000	500	16.9	92	8,000	c 1,440	82,000	2 to 12	4.8	5.5
Empire mine:										
Butyl mercaptan	500	500	16.9	90	3,600	1,000	40,000	300	9.8	11.5
Central mine:										
Amyl acetate	1,000	1,000	33.8	80	3,500	1,000	40,000	300	20.1	23.0

Mine and material.	Observer 1.	Observer 2.	Observer 3.	Observer 4.	Observer 5.	Remarks.
North Butte mine:						
Ethyl mercaptan	*4,000 feet by pipe.* 15:00	*4,000 feet by pipe.* 15:00	*4,300 feet by pipe.* 15:00	....	....	Injector was set 25 feet above air pipe on 1-inch pipe connection.
Butyl mercaptan	120:00	120:00	120:00	....	....	Do.
Amyl acetate	3:00	3:00	3:00	....	....	Injector was set immediately above air line.
Empire mine:						
Butyl mercaptan	*5,000 feet by pipe.* 10:00	*7,000 feet by pipe.* 5:00	*6,000 feet by pipe.* 5:00	*3,800 feet by pipe.* 4:00	*7,800 feet by pipe.* 8:00	More butyl mercaptan used than recommended.
Central mine:						
Amyl acetate	*4,000 feet by pipe.* 3:00	*4,800 feet by pipe.* 10:00	*3,600 feet by pipe.* 7:00	*3,800 feet by pipe.* 4:00	*7,800 feet by pipe.* 8:00	More amyl acetate used than recommended.

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[a] At pit mouth odor was faint and recognition would not have been certain if the odor had been unexpected. Inside mine at openings of air pipes odor was strong and distinct.

[b] Leak in pipe was under water. Stench came through the water.

[c] Estimated from rate of travel of stench.

The tests in the California mines were conducted with more stench material than was recommended. In the tests of butyl mercaptan 11.5 c. c. per 1,000 cubic feet of air were used, whereas 5 c. c. per 1,000 cubic feet of air is sufficient. However, the men in the mine were not bothered by the stronger concentrations. The time required for the stench to reach the observers varied from 3 to 10 minutes, and the odor was carried to all parts of the mine in 20 minutes. Both tests proved highly successful.

In the tests described, stench-laden air escaped from machines or from definite openings in the pipe lines. However, in practically every stope of a metal mine, the air pipes, valves, or joints have leaks sufficient to liberate the stench, so that even if machines were not running the men would receive the warning.

CHARACTERISTICS OF THE STENCHES USED IN MINE TESTS.

The characteristics of the materials used in the mine tests are as follows:

BUTYL MERCAPTAN.

Butyl mercaptan has a powerful and exceedingly disagreeable odor, even when used in small concentrations. The odor is characteristic of this substance and will not be confused with any odors commonly found in mines. The rapidity of evaporation is moderate; therefore, there is little danger of getting too strong a concentration. If the substance is used in excessive quantities, it is difficult to clear the mine of the odor. The chief disadvantage to using butyl mercaptan as a stench warning in mines is that it can not be obtained in the market at present, but a manufacturer is experimenting with a view to producing it. Butyl mercaptan can be made in the laboratory, and, if desired, instructions for preparing it will be furnished by the Bureau of Mines.

ETHYL MERCAPTAN.

Ethyl mercaptan is also an excellent stench, having a disagreeable and characteristic odor. Ethyl mercaptan evaporates rapidly, however, and care should be taken not to use it in greater concentrations than given in Table 5 on page 25 following. When not in use it should be kept in a tight container. Ethyl mercaptan may be obtained in the market in 1-gallon cans or 5-gallon drums.

AMYL ACETATE.

Amyl acetate, which is artificial banana oil, evaporates readily and gives a rapid and sure warning throughout a mine. The odor is rather pleasant to most people, and therefore is not so suitable a warning as one more disagreeable. Amyl acetate is inexpensive and can be readily obtained from any paint dealer or chemical supply house in quantities desired.

BUTYRIC ACID.

Butyric acid is readily obtainable in the market. Unless the concentration used is large, however, the odor may not be distinguishable from other odors existing in mines. The odor is very unpleasant when strong, but is not nearly so disagreeable as that of the mercaptans. Butyric acid evaporates slowly, as compared with the mercaptans and the amyl acetate, and difficulty might be experienced in having the air take up enough to thoroughly permeate a very large mine, or one using a large quantity of air in the ventilating current.

VALERIC ACID.

Valeric acid, which may be readily obtained, has about the same properties as a warning stench as butyric acid. The odor, however, is not easily distinguished from mine odors. This substance evaporates much more slowly than butyric acid, and strong concentrations in air are difficult to obtain. Where the ratio of ventilating current to compressed air is high, it would probably be impossible to pass enough of the material through the air line to obtain the desired concentration throughout the ventilating current.

HARMLESSNESS OF THE STENCHES.

All of the above substances are known to be harmless, even in strong concentrations. When the tests were made in the experimental mine, the men were told to go to fresh air if affected by the smell, but they all stayed in their places. They knew that a small quantity was to be used and expected the odor to last only a short time. One man complained of a slight headache during the first test, in which butyl mercaptan was used, but this passed away after he had been assured that the vapor was harmless.

RESULTS OF MINE TESTS WITH DIFFERENT CONCENTRATIONS OF BUTYL MERCAPTAN.

A series of tests was made in the experimental mine with different quantities of butyl mercaptan in order to determine the minimum amount that could be positively detected. The results, which are shown in table 4, indicate when very small quantities are used the resulting odor is not as strong as might be expected from the calculations. This is due to losses at various points along the compressed-air line. In the tests with the smaller quantities, the usual rate of injection could not be maintained, resulting in a rather weak and unsatisfactory warning.

In the test in which 10 c. c. was used, the odor was readily observable near the opening of the compressed-air pipe, but was rather weak when the escaping air became diluted with the fresh air of the ventilating current. Using the same relative concentration where a larger quantity of air is used or where the ratio of ventilating current to compressed air is lower should give a fairly positive warning.

TABLE 4.—*Results of tests with various concentrations of butyl mercaptan.*

Item.	Test 1.	Test 2.	Test 3.	Test 4.
Quantity of liquid used, c. c.	65	20	10	5
Rate of injection, c. c. per minute	29.8	26.7	25.0	15.8
Pressure on air line at compressor, pounds per square inch	72	25	70	65
Estimated quantity of free air passing through compressed-air line, cubic feet per minute	50	74	54	43
Estimated average velocity of air passing through pipes, cubic feet per minute	390	1,241	427	359
Quantity of air in ventilating current in mine, cubic feet per minute	5,000	5,000	6,120	4,000
Average velocity of ventilating current, cubic feet per minute	84	84	103	67
Concentration in ventilating current:				
Milligrams per cubic foot	5.06	4.51	3.47	3.35
C. c. per 1,000 cubic feet	5.90	5.26	4.05	3.91
Observer 1:				
Station at ... A 650				
Pipe length ... 1,135 feet				
Observer stationed at pipe opening.				
	M. S.	*M. S.*	*M. S.*	*M. S.*
Time required for odor to reach station	5 26	0 55	2 35	3 5
Observer 2:				
Station at ... 1 B 100				
Pipe length ... 1,470 feet				
Observer stationed at pipe opening.				
Time required for odor to reach station	7 00	1 45	5 33	4 23
Observer 3a:				
Station at ... 1 B 400				
Pipe length ... 1,760 feet				
Observer stationed at pipe opening.				
Time required for odor to reach station	5 33	....	....	....
Observer 3b:				
Station at ... 2 B 375				
Pipe length ... 1,786 feet				
Observer stationed at pipe opening.				
Time required for odor to reach station	....	0 16	5 00	5 10
Observer 4:				
Station at ... 2 B 290				
Pipe length ... 1,736 feet				
Observer stationed at pipe opening.				
Time required for odor to reach station	11 20	4 20	11 15	12 15
Observer 5:				
Station at ... 5 R 175				
Pipe length ... 1,485 feet				
Distance on ventilating current odor had to travel from pipe opening to reach observer ... 300 feet				
Time required for odor to reach observer	16 16	6 43	23 35	19 25
Observer 6:				
Station at ... E 0				
Pipe length ... 1,760 feet				
Distance on ventilating current odor had to travel to reach observer ... 2,000 feet				
Time required for odor to reach observer	33 25	43 02	29 00	34 00
Remarks	(a)	(b)	(c)	(d)

[a] Strong and disagreeable odor difficult to clear from mine.
[b] Strong, disagreeable odor
[c] Odor noticeable but not strong.
[d] Odor weak and uncertain.

METHODS OF USING THE STENCHES IN MINES.

INJECTOR.

Any pressure oil-cup device that permits the liquid to be placed in the compressed air pipe against the air pressure will be satisfactory for introducing stenches. The sight-feed glass shown in figure 4 (p. 14) is recommended, because the operator can see that the material is entering properly. The discharge valve should be so arranged that it will open only far enough to permit the proper rate of flow. This rate can be determined by trying with the same volume of water, but such tests should be conducted with all the usual connections made to the air line and with pressure on. Some convenient arrangement should be made for pouring the chemical into the injector, such as the filling plug shown in figure 4. Ordinary fly screen may be used beneath the injector. The finer the mesh the better, if it does not obstruct the flow of air. The screen should be placed at an angle, as shown.

POSITION OF INJECTOR.

The injector should be placed on the discharge side of the compressor and receiver, in order that the chemical will not pass through any machinery or be held in storage reservoirs.

It has been suggested that the stench be put into the inlet of the compressor so that the entering air would take up the stench. There are reasons why this is not advisable: The substances that are most suitable for stenches are solvents for lubricating oil. If the stench is introduced into the intake side of the compressor, some of it may be carried into the cylinder as liquid, or the vapors may condense to liquid under compression. This liquid would cut the oil in the cylinder and destroy its lubricating properties; also, certain packings might be harmed by it. If the stench is introduced into the pressure side of the line, there will be no danger of the vapors attacking any lubricating oils, packing, or other materials in the parts through which the air must pass.

The injector should be placed in a removable section so that after being used the injector can be taken out and cleaned of any excess material. This section should preferably be larger than the main line, in order to get a lower velocity of air passing through the screen, and prevent drops of the liquid being blown off and deposited in the bottom of the pipe. Also, this section should be in a by-pass with valves at both ends and with a valve in the main line, so that all the air may be forced through the screen. After use, the valves on the by-pass should be closed as quickly as the main line can be opened, in order to prevent any excess stench from being carried into the air line, if too much should have been dropped on the screen.

QUANTITY OF CHEMICAL TO BE USED.

The quantity of chemical necessary to give a positive warning in any given mine can not be determined beforehand with accuracy, because of the many factors involved. If the compressed air is fairly evenly distributed throughout the mine and the volume of air supplied by the ventilating current is large, compared to the volume of compressed air, enough of the chemical should be put into the mine in one minute to impart a strong odor to all the air passing through the mine in the same period. If, however. a large proportion of the compressed air goes to that area of the mine which has little ventilation and only a small part of the air to the areas having relatively large ventilation, the former area would receive a very strong odor while the latter would receive a comparatively weak odor. In this event the quantity of chemical would have to be increased to take care of the strongly ventilated areas.

Where there is no ventilation other than that due to displacement by the compressed air, the quantity of liquid to be used will depend upon the ratio of the volume of air supplied to the volume of the working place that it is desired to fill. The odor from a stench will gradually diffuse through a large area, even in perfectly still air, but this takes a relatively long time. Where men are scattered throughout workings with no ventilation, as in many metal mines, it would be better to have the " leaks " in the air line near the men farthest from the mine opening and have these men on their way out warn the others.

Taking into consideration these various factors, data have been given in Table 5 by which the amount of each of the substances that may be used can be calculated for any mine when the ventilation is known. It is believed that these quantities will give satisfactory results in practically all mines, but the quantities may be changed to conform to unusual conditions. Very little advantage, if any, will be gained by using larger quantities than are recommended in this table. and it will be much more difficult to clear the mine after using the larger amounts. Whatever quantity is used should always be injected during an interval of one minute.

TABLE 5.—*Quantity of different stenches to use per 1,000 cubic feet of free air per minute entering mine (compressed air and ventilating current). The total amount to be used is to be injected in one minute.*

Chemical.	Quantity, c. c.	Remarks.
Butyl mercaptan......	5	Gives excellent results but can not be obtained in the market at present.
Ethyl mercaptan......	8	Can be obtained in the market. Boiling point is very low; requires care not to exceed amount indicated. Must be kept hermetically sealed until ready for use.
Amyl acetate.........	16	Readily obtainable in the market, but the odor is not disagreeable.
Butyric acid..........	12	Readily obtainable, but may escape detection in the odors common to mines.
Valeric acid...........	40	Readily obtainable, but may escape detection in the odors common to mines. Difficult to obtain a sufficiently high concentration because of slow evaporation.

The column of figures in Table 5 shows the number of cubic centimeters of liquid chemical to be used for each 1,000 cubic feet of air going through the mine.

The total amount of free air going through the mine per minute should be determined approximately. This will include the ventilating current, if there is any, whether it be artificial or natural, and also the amount of free air being sent through the compressed-air line. The latter may be determined closely enough by multiplying the volume of the air cylinders of the compressor by the number of revolutions per minute. The pressure carried on the air line does not enter into the calculation. As a rule, if the mine is well ventilated, the amount of compressed air is negligible compared to the total quantity of air entering the mine. The number of thousands of cubic feet of air passing through the mine per minute should be multiplied by the factor given in Table 5, which will give the total quantity of stench to be used. This total quantity should be injected into the air line during a period of as nearly 60 seconds as can be regulated. For example: If a mine uses a total of 12,000 cubic feet of air per minute, the quantity of ethyl mercaptan that should be used for a warning in that mine would be 8×12=96 cubic centimeters of the liquid. This quantity of the material may be kept in the injector ready for use, provided there are no leaks in the injector, and especially no leaks in the by-pass valves. The regulating valve in the bottom of the injector should be so arranged that when wide open the total measured quantity of stench will be discharged in 60 seconds. This may be tried out beforehand with water, as mentioned on page 23.

It may be possible in some instances that the volume of air in the ventilating current is so large compared to the volume of compressed air that the latter can not carry enough of the chemical to make a strong odor when diluted with the ventilating current. This condition is probably never reached in practice. If such a condition should be found, the odor would be weak in the air ways, but would still be strong enough in the poorly ventilated parts of the mine to give an adequate warning. The excess chemical used would remain on the screen or in the pipe as a liquid, and should be cleaned out before the next warning.

Should such a case arise, it would be of advantage to use one of the more volatile liquids, as shown by the low boiling points given in Table 2, page 11. Ethyl mercaptan would be particularly serviceable.

WARNINGS IN WINTER.

The tests at the experimental mine, described herein, were performed in summer. Those at the North Butte mine were performed in February, when the outdoor temperature was 24° F., and that of the air in the pipes at the point of injection was 93° F. It is possible that, in cold winter weather, with cold air in the pipes at the stench injector, different results would be obtained on account of the lower vapor pressures at low temperatures. Where the pipe line is exposed to extremely cold weather, ethyl mercaptan should be used in order to obtain sufficiently rapid evaporation, because the other less volatile compounds might be condensed in passing through the cold pipe.

At cold winter temperatures, amyl acetate may give trouble by flowing more sluggishly. No trouble would be experienced, however, at the usual engine-room temperatures.

CLEANING THE INJECTOR.

After the apparatus has been used for sending a warning, it should be taken apart and thoroughly cleaned, particular care being taken to see that none of the liquid remains in the pipe. This is to prevent the possibility of an excess quantity being used in a subsequent warning.

TRAINING MINERS TO DETECT ODOR.

If it is desired to teach the miners the nature of the odor to be used as a warning this should be done by having them smell vapor issuing from a nozzle or other small outlet, and not by putting them into a room where the air is saturated with the odor. If the latter method is used, the miner's garments, unless thoroughly aired, might carry enough of the vapor to give a false warning later in the day.

SUMMARY.

1. The placing of stenches in the compressed-air lines of a mine, to warn miners of danger, offers certain advantages over the use of electric bells or other means of warning. Among these advantages

are convenience of installation, reliability of action, and positive effect upon the miners, the natural instinct being to flee from the ill-smelling air to pure air.

2. An apparatus or "odorometer" for measuring intensity of odors was devised for the laboratory examination of various stenches.

3. Of 24 chemicals examined, butyl mercaptan, ethyl mercaptan, amyl acetate, butyric acid, and valeric acid were found most promising for mine warnings.

4. Tests performed in mines showed that a quick and positive warning could be given with these materials.

5. A simple apparatus, or injector, has been devised for introducing the liquid chemicals into compressed-air lines of mines.

6. Instructions for the use of the chemicals and the injector have been given.

7. It is important that good ventilation be established to clear mines of the stench after a warning.

PUBLICATIONS ON SAFETY IN MINING.

A limited supply of the following publications of the Bureau of Mines has been printed and is available for free distribution until the edition is exhausted. Requests for all publications can not be granted, and to insure equitable distribution applicants are requested to limit their selection to publications that may be of especial interest. Requests for publications should be addressed to the Director, Bureau of Mines.

The Bureau of Mines issues a list showing all its publications available for free distribution as well as those obtainable only from the Superintendent of Documents, Government Printing Office, on payment of the price of printing. Interested persons should apply to the Director, Bureau of Mines, for a copy of the latest list.

PUBLICATIONS AVAILABLE FOR FREE DISTRIBUTION.

BULLETIN 17. A primer on explosives for coal miners, by C. E. Munroe and Clarence Hall. 1911. 61 pp., 10 pls., 12 figs.

BULLETIN 20. The explosibility of coal dust, by G. S. Rice, with chapters by J. C. W. Frazer, Axel Larsen, Frank Haas, and Carl Scholz. 1911. 204 pp., 14 pls., 28 figs.

BULLETIN 42. The sampling and examination of mine gases and natural gas, by G. A. Burrell and F. M. Seibert. 1913. 116 pp., 2 pls., 23 figs.

BULLETIN 46. An investigation of explosion-proof mine motors, by H. H. Clark. 1912. 44 pp., 6 pls., 14 figs.

BULLETIN 48. The selection of explosives used in engineering and mining operations, by Clarence Hall and S. P. Howell. 1914. 50 pp., 3 pls., 7 figs.

BULLETIN 50. A laboratory study of the inflammability of coal dust, by J. C. W. Frazer, E. J. Hoffman, and L. A. Scholl, jr. 1913. 60 pp., 95 figs.

BULLETIN 52. Ignition of mine gases by the filaments of incandescent electric lamps, by H. H. Clark and L. C. Ilsley. 1913. 31 pp., 6 pls., 2 figs.

BULLETIN 56. First series of coal-dust explosion tests in the experimental mine, by G. S. Rice, L. M. Jones, J. K. Clement, and W. L. Egy. 1913. 115 pp., 12 pls., 28 figs.

BULLETIN 57. Safety and efficiency in mine tunneling, by D. W. Brunton and J. A. Davis. 1914. 271 pp., 6 pls., 45 figs.

BULLETIN 62. National mine rescue and first aid conference, Pittsburgh, Pa., September 23–26, 1912, by H. M. Wilson. 1913. 74 pp.

BULLETIN 68. Electric switches for use in gaseous mines, by H. H. Clark and R. W. Crocker. 1913. 40 pp., 6 pls.

BULLETIN 74. Gasoline mine locomotives in relation to safety and health, by O. P. Hood and R. H. Kudlich, with a chapter on methods of analyzing exhaust gases, by G. A. Burrell. 1915. 83 pp., 3 pls., 27 figs.

BULLETIN 75. Rules and regulations for metal mines, by W. R. Ingalls and others. 1915. 296 pp., 1 fig.

Original from PRINCETON UNIVERSITY

BULLETIN 80. A primer on explosives for metal mines and quarrymen, by C. E. Munroe and Clarence Hall. 1915. 125 pp., 51 pls., 17 figs.

BULLETIN 132. Siliceous dust in relation to pulmonary disease among miners in the Joplin district, Missouri, by Edwin Higgins, A. J. Lanza, F. B. Laney, and G. S. Rice. 1917. 116 pp., 16 pls., 6 figs.

BULLETIN 139. Control of hookworm infection at the deep gold mines of the Mother Lode, California, by J. G. Cumming and J. H. White. 1917. 52 pp., 1 pl., 5 figs.

BULLETIN 99. Mine-ventilation stoppings, with especial reference to coal mines in Illinois, by R. Y. Williams. 1915. 30 pp., 4 pls., 4 figs.

BULLETIN 102. The inflammability of Illinois coal dusts, by J. K. Clement and L. A. Scholl, jr. 1916. 74 pp., 5 pls., 22 figs.

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